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ORIGINAL ARTICLE

Comparison of shear bond strength of rebonded brackets with four methods of adhesive removal

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Abstract Rebonding of a dislodge bracket is considered as an economic saving option which can be done with use of in-office methods or by commercial recycling. The aim of this study was to compare the shear rebond strength (SRS) of brackets recycled with different resin removal methods. Eighty premolars were divided into four experimental groups. The teeth were bonded with metal brackets. The brackets were debonded and adhesive remnants were removed from bracket bases by means of Er:YAG laser, sandblasting, direct flame, and CO2 laser, respectively. Following adhesive removal from enamel surfaces with carbide bur, recycled brackets were rebonded. Finally, all brackets were debonded with a Dartec testing machine and the SRS values were determined. The SRS values of groups 3 and 4 were significantly lower compare to other groups (*P* value< 0.001). SEM examination showed complete adhesive removal from bracket base cleaned with Er:YAG laser irradiation. Microroughening of the base of sandblasted bracket was observed in the SEM image. Resin removal with direct flame and CO2 laser irradiation was incomplete. Er:YAG laser recycling of brackets is an efficient in-office method of reconditioning which caused minimum damage to the bracket base.

Keywords Er:YAG laser · Co2 laser · Rebonding · Shear bond strength

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Introduction

One of the problems observed in the course of orthodontic treatment is bond failure at bonding interface between enamel and bracket, which has been reported to occur up to 17.6 % [1–3]. Eminkahyagil et al. reported that one out of every five bonded brackets came loose during orthodontic treatment [4]. Bond failure may occur as a result of sudden force applied by patients to the attachments or because of poor bonding technique [5]. Bond failure is also affected by other factors including tooth type, bracket type, and design and occlusal forces [1]. Various attempts have been made to achieve higher shear bond strength (SBS) and lower bond failure which lead to development of new techniques and materials. Bonding of brackets by means of techniques which yielded optimal bond strength in vitro makes them capable of bearing occlusal forces [6].

It is sometimes needed to rebond brackets which are debonded inadvertently because of bond failure or intentionally for correction of their position [7]. Rebonding of a dislodge bracket is considered as an economic saving option which can be done with use of in-office methods or by commercial recycling. However, because of time consuming process of commercial recycling, in-office reconditioning is preferred option [8]. The SBS of a recycled bracket is affected by several factors including microscopic damage to the bracket base [9] bracket base design [10] and amount of remaining adhesive on the bracket base [10, 11] as well as the method used for adhesive removal [9, 10, 12, 13].

Adhesive removal from a bracket base is conventionally done by means of green stones [12] gas torch [12] and sand blasting [9, 10, 12, 13]. Laser recycling has been discussed in limited number of researches recently. In recent years, there has been an increasing interest in laser application in dentistry. The first laser introduced to dentistry was Nd:YAG laser. In 1997 Er:YAG laser was approved by the U. S. Food and Drug Administration for dental hard tissues application [14]. Orthodontic applications of lasers have been reported in literature as enamel etching [15], adhesive removal from debonded brackets [16], pain relief [17], and acceleration of orthodontic tooth movement [18]. The objective of the present study was to determine the effects of different resin removal methods on SBS of rebonded brackets.

Materials and methods

A total of 100 premolar teeth extracted for orthodontic purposes were cleaned and stored in distilled water, then immersed in 0.1 % thymol solution at room temperature for a week. The teeth were free of caries, restorations, and enamel defects and none of them had previous endodontic treatment. All samples were examined under dental unit lamp and cracked teeth were excluded from the study.

Initial bonding procedure

The buccal surfaces of teeth were cleaned using nonfluoridated pumice powder and rubber prophylactic cups for 15 s, rinsed and dried with air spray. After cleaning, the teeth were conditioned with a 37 % phosphoric acid gel (Fine Etch, Korea) for 20 s and dried with oil and moisture free air until the frosty white appearance was achieved. Stainless steel standard edgewise premolar brackets were used in this study (Dentaurum Company, Ispringen, Germany). After etching process, a thin adhesive resin layer (Resilience, Orthotechnology, Florida, USA) was applied on the buccal surfaces of teeth and the bracket bases were coated with a composite resin (Resilience, Orthotechnology). The brackets were positioned at 4 mm distance from the buccal cusp tip using a special gauge. Following removal of excessive composite resin with a dental explorer adhesive was cured using light-emitting diode (Curing, Morita, Japan) for 20 s (5 s for each occlusal, gingival, mesial, and distal direction).

Teeth grouping

The teeth were randomly divided into five groups. The brackets in the first four groups were debonded with use of a removing plier (Dentaurum, Germany) as recommended by the manufacturer and clean up of adhesive was done with Er:YAG laser, sandblasting, flame, and CO2 laser, respectively. In the fifth group, teeth were mounted in blocks of self curing acrylic resin (Marlik, Iran, Tehran) and debonding procedure was performed by a DARTEC testing machine (Dartec HC10, England) using a crosshead speed of 0.5 mm/min and 0.5 mm blade thickness, and shear force needed to achieve bond failure was recorded.

The teeth enamel surfaces in all study groups were cleaned of adhesive remnants using 12 fluted carbide burs with moderate speed. Adhesive removal was considered complete when all visible residues were removed.

Adhesive removal from bracket base:

The brackets in the first four groups were reconditioned using different techniques which were as follows:

Group 1: The adhesive removal was done by an Er:YAG laser device (Fontona–1210 Ljubijana, Slovenia) with wave length of 2,940 nm. A spot size of 0.9 mm and a RO2-C headpiece were used. The laser was operated at pulse mode (medium short pulse) at a distance of 5–7 mm perpendicular to the bracket bases. Average power output was 5.5 W and the laser was used at 275 mJ and 20 Hz for 25 s with air and water cooling spray.

Group 2: The brackets were sandblasted (Renfert, Germany) with 50 μm aluminum oxide particles at 75 psi for 4 s. The bracket bases were held approximately 10 mm from the sandblaster device.

Group 3: The brackets were heated on a gas torch for 5 s to a cherry red color, then quenched in water and composite remnants were removed with a dental explorer.

Group 4: A CO2 laser (DSE, Seoul, Korea) was used for recycling of the brackets in this group. The laser with wavelength of 10,600 nm operated at pulse mode with output power of 5 W, repeating time of 100 mS and pulse duration of 50 mS with spot size of 0.1 mm. The laser device tip was held at 2–3 mm distance and irradiation was performed for 1.5 min.

Rebonding procedure

Teeth conditioning with 37 % phosphoric acid was done as mentioned before, except that no rubber cup prophylaxis of the enamel surfaces was performed prior to the etching process. Rebonding of the recycled brackets was done as with initial bonding in the groups 1–4. In the fifth group, new brackets were bonded to the teeth. The teeth in groups 1–4 were mounted in the self-curing acrylic resin blocks exposing only the crown portion. The teeth in group 5 had been mounted in the acrylic resin blocks as mentioned previously. The specimens were stored in normal saline until shear bond strength testing.

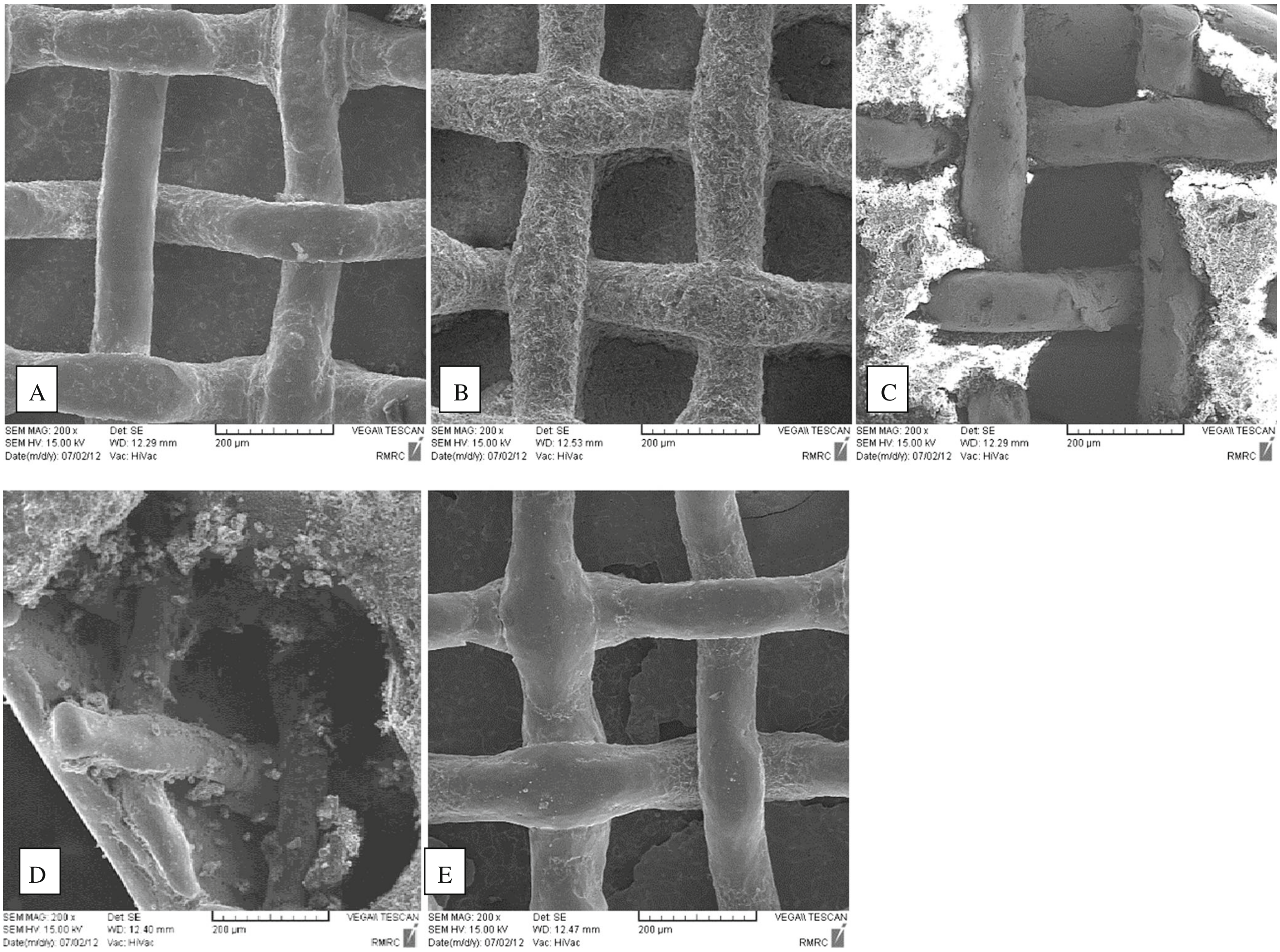

Fig. 1 One recycled bracket from each of the first four groups along with a new bracket as a control. **a** Er:YAG laser, **b** sandblasting, **c** flame, **d** Co2 laser, **e** new bracket

Shear bond strength testing

After 48 h of rebounding, the shear rebond strength (SRS) testing was performed by the DARTEC testing machine. The teeth were positioned in a manner that line of force application was perpendicular to the bracket bases. The SRS was measured by crosshead speed of 0.5 mm/min of the testing machine and the teeth were stressed until bond failure. Force required to achieve bond failure was recorded in Newtons and later converted to megapascal by dividing the value of force by the bracket base area which was 12.09 mm^2

Scanning electron microscope examination

One recycled bracket from each of the first four groups along with a new bracket as a control were inspected under a scanning electron microscope (SEM, VEGA, TSCAN) at ×200 magnification and voltage of 15 kW (Fig. 1).

Adhesive remnant index

After final debonding, the enamel surfaces were examined under a stereomicroscope at ×10 magnification to evaluate the amount of remaining adhesive. The amounts of residual adhesive were scored using adhesive remnant index (ARI) of Oliver [19]. Score 1 indicated that all adhesive remained on the enamel surface, score 2 indicated that more than 90 %

Table 1 Shear bond strengths of six groups

Groups		Mean	SD	Range
1	Er:YAG	11.23	2.3	10.15–12.31
2	Sandblasting	12.59	2.25	11.53–13.64
3	Flame	6.95	1.69	6.16–7.74
4	CO2	3.14	1.64	2.38–3.91
5	Control 1	11.46	2.16	10.45–12.48
6	Control 2	11.36	2.13	10.36–12.36

Table 2 Comparison of shear bond strength between groups

	1		2		3		4		5		6	
	P value	Sig	*P* value	Sig	*P* value	Sig	*P* value	Sig	*P* value	Sig	*P* value	Sig
1	–	–	0.299	ns	0.000	*	0.000	*	0.999	ns	1.000	ns
2	0.299	ns	–	–	0.000	*	0.000	*	0.514	ns	0.416	ns
3	<0.001	*	0.000	*	–	–	0.000	*	0.000	*	0.000	*
4	<0.001	*	0.000	*	0.000	*	–	–	0.000	*	0.000	*
5	0.999	ns	0.514	Ns	0.000	*	0.000	*	–	–	1.000	ns
6	1.000	ns	0.416	Ns	0.000	*	0.000	*	1.000	ns	–	–

ns not significant

**P* value<0.05

of the adhesive remained on the enamel surface, score 3 revealed that between 10 and 90 % of the adhesive remained on the enamel surface, score 4 showed that less than 10 % of the adhesive remained on the enamel surface, and score 5 implied that no adhesive remained on the enamel surface.

Statistical analysis

Descriptive statistics including mean and standard deviation of SBS values were calculated by means of statistical package for social sciences (SPSS for windows, release 10.0.0, Chicago, IL, USA). The Kolmogorov–Smirnov test showed normal distribution of data. The ANOVA and Tukey's tests were used for multiple comparisons of SBS amounts between the groups. To evaluate differences in ARI scores the Kruskal–Wallis test was used. $P \leq 0.05$ was considered significant for all statistical tests.

Results

The shear bond strengths of the new brackets (controls 1 and 2) were considered as a baseline according which the bond strengths of the reconditioned brackets were measured.

Table 3 Distribution of ARI Scores

Groups		ARI scores				
		1	2	3	4	5
1	Er:YAG	–	–	5	9	6
2	Sandblasting	–	–	2	8	10
3	Flame	7	8	4	1	–
4	Co2	10	9	1	–	–
5	Control 1	–	–	4	9	7
6	Control 2	–	–	4	10	6

As presented in Table 1, the brackets cleaned with the sandblaster device produced the highest SRS (12.59±2.25 MPa) and those recycled by the CO2 laser irradiation produced the lowest SRS (3.14±1.64 MPa) among the groups. Although the mean SRS value of sandblasted brackets was the highest among the groups, it did not differ significantly from that of the Er:YAG laser recycled (11.23±2.3 MPa) and the control groups (5 and 6; 11.46±2.16 and 11.36±2.13 MPa; $P>0.05$). As can be seen from Table 2, the SRS values of the flamed brackets and the CO2 laser recycled brackets were 6.95±1.69 and 3.14±1.64 MPa, respectively, which were significantly different from other groups and from each other ($P<0.05$).

Results of SEM examination indicated that the base of Er:YAG laser recycled bracket resembled a new bracket base which its meshwork was completely free of adhesive remnants. SEM images taken from the base of sandblasted bracket revealed slight amount of adhesive remaining and microroughening of the bracket base. As can be seen from SEM images, adhesives were left more on the CO2 laser recycled bracket compared to the flamed bracket.

Frequencies of ARI scores for each of the groups are shown in Table 3. As can be seen from Table 3, bond failure mode of the control, sandblast, and Er:YAG laser groups were similar together. Most of specimens (more than 70 %) showed ARI scores of 4 and 5 in the aforementioned groups which meant bond failure was mostly occurred in the enamel–adhesive interface. In the flame and CO2 groups, bond failure was mostly seen in the bracket–adhesive interface which corresponded to ARI scores of 1 and 2.

Discussion

Bracket reconditioning aims at complete removal of residual adhesive from bracket base without causing damage to it or distorting the slot dimensions. Furthermore, optimal clinical

SBS should be provided. Although optimal bond strength needed for clinical purpose is not clear yet, bond strength should be high enough to make the brackets capable of withstanding masticatory forces. On the other hand, bond strength should not be too much to compromise easy and safe debonding at the end of treatment. Minimum clinically acceptable SBS has been reported to be 5.9 MPa by Reynold et al. [20].

As described previously, mean SRS of the sandblasted brackets was not significantly higher than those of the Er:YAG laser recycled brackets and the control groups, though it was highest among the groups. These findings are in line with results of studies done by Ishida [21], Basudan [12], Chetan and Muralidhar Reddy [8], Sonis [22], and Grabouski [23].

Higher SRS values of the sandblasted brackets can be attributed to microroughening of the bracket base produced by AL2O3 particles which is supported by findings of Willems et al. [10] who showed that enhanced bonding surface resulted from micro roughening of bracket base could increase SBS values. However, these observations are contrary to what Chung [13] and Regan [24] found. They reported lower SBS values for sandblasted group. This difference can be explained by variation in AL2O3 particle size and sandblasting duration in different studies. As Milllett [10] and Aricit [25] pointed out that adequate duration of sandblasting increased SBS values but sandblasting for longer duration or with larger particles resulted in bracket base distortion and subsequent decrease in SBS values. This also accords with our observations in SEM images which showed bracket base damage in the sandblasted group that could be avoided by using shorter sandblasting duration.

The Er:YAG laser recycled brackets showed comparable SRS to the control groups which is further supported by SEM images. As can be seen from Fig. 1a adhesive are completely cleaned from the base of Er:YAG lased brackets. Aforementioned findings are corroborated by Ishida's findings with Er:Cr:YSGG laser [21]

Considerable amounts of adhesive remnants were left on the base of CO2 laser-irradiated brackets. SRS of the CO2 lased brackets fell under optimal range of clinically acceptable bond strength. Therefore, results of this study showed that CO2 laser irradiation cannot be considered as an appropriate recycling method. The flamed brackets yielded significantly higher SRS compared to the CO2 laser-irradiated brackets. The mean SRS of flamed brackets, though lower than that of the Er:YAG lased brackets and the control groups, was clinically acceptable. Remaining of adhesive on bracket base lessen the contact area between meshwork and adhesive and lead to decrease in SRS value. Our results are consistent with those of Chetan and Muralidhar Reddy [8] in this regard.

The bond failure in the groups 1, 2, 5, and 6 was occurred mostly in the enamel–adhesive interface. This observation demonstrated that the sandblasted brackets and the Er:YAG laser recycled brackets provided mechanical interlock between bracket base and adhesive which was similar to the new brackets, and can also be an explanation for higher shear bond strength of brackets in the sandblast and the Er:YAG laser groups. Higher frequency of bond failure in the bracket–adhesive interface in the groups 3 and 4 can be explained with remaining of adhesive on the bracket base and inappropriate mechanical bond between bracket base and adhesive which also leaded to lower values of SBS in these groups.

In comparing of different residual resin clean-up methods used in this study, sandblasting was the least time-consuming procedure. In-office use of this method requires precise control on duration of sandblasting to prevent possible damage to bracket base. Adequate ventilation is also needed.

Heating the brackets to burn off residual composite resin from bracket base causes discoloration of brackets which is undesirable for most of patients and imposes the risk of toxic fumes inhalation which are product of composite incineration process. Furthermore, heating process makes brackets vulnerable to damage under masticatory forces. The gas torch heating method may affect the physical properties of the metal of the brackets.

Chetan reported that heating procedure lessened bracket hardness [8]; however, Buchman [26] showed that decrease in bracket hardness due to heating process was of little clinical importance. Co2 laser irradiation is not suitable for recycling of brackets because of its high cost and low efficiency.

Our results showed that Er:YAG laser irradiation is the most clinically efficient method of residual resin clean-up. By using Er:YAG laser for recycling of brackets, all residual adhesive can be removed in 25 s without causing damage to bracket base and Er:YAG laser recycled brackets resemble new brackets. This method is an efficient method for in-office recycling but requires special safety principles to be considered.

Conclusions

1. The Er:YAG laser recycled brackets yielded SRS values comparable to those of the sandblasted brackets and the control groups.
2. Mean SRS of the flamed brackets, though significantly lower than control groups, exceeded minimum clinically adequate level.

3. The Co2 laser recycled brackets produced the lowest SRS among the groups which fell under clinically acceptable range.
4. Er:YAG laser recycling of brackets was the most efficient method which caused minimum damage to the bracket base.

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